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REMOTE SENSING OF EFFECTS OF LAND-USE
PRACTICES ON WATER QUALITY

Annual Report-Contract No. NAS8-31006

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INTRODUCTION

Under the auspices of the University of Kentucky Research Foundation, Lexington, Kentucky, the Department of Forestry began a cooperative research effort with the National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama on October 11, 1974. This contract, NAS8-31006, was to be in effect until December 10, 1975, but has since been extended to December 10, 1976.

Research objectives under this contract are:

1. To establish ground truth parameters that represent the vegetative cover of disturbed and undisturbed watersheds in the Cumberland Plateau of eastern Kentucky.
2. To monitor several water quality parameters of the watersheds utilized in the establishment of ground truth data.
3. To evaluate the capabilities of multistage-multispectral aerial photography and satellite imagery in detecting various land use practices.
4. To establish photographic signatures of known land use areas utilizing manually-operated spot densitometers.
5. To determine correlation of imagery signature data to water quality data.
6. To develop potential water quality predictions from forested and non-forested watersheds based upon above correlations.
7. To evaluate cost effectiveness of predicting water quality values utilizing multistage and satellite imagery sampling techniques.

Additional implied objectives are (1) evaluation of potential utility of densitometry and color additive viewing for yielding information pertinent to the needs of various state agencies and (2) dissemination to these agencies and other interested user groups of this and other relevant information gained from this research project.

STUDY AREA

Six watersheds having a total area of 539 hectares (1330 acres) comprise the study area. All six study watersheds are forested but two have been partially surface mined. One watershed has been fertilized with ammonium nitrate and another is tentatively scheduled for logging in the summer of 1976. The other two watersheds are being utilized as controls.

The study area, as first proposed, included five watersheds totaling 7,490 hectares (18,500 acres). Time and funding constraints, as well as loss of two weirs due to flooding and siltation, necessitated the reduction in study area size.

STUDY ACTIVITY

Personnel additions

Mr. Mahlon Hammetter was hired on December 1, 1974 to serve as photo interpreter for the project. Dr. George Coltharp came to the Department of Forestry in January, 1975 as Associate Professor to work in the area of forest hydrology. He was then added to the project as co-investigator.

Ground truth

Forest types were delineated by species, size, and density classes utilizing photo interpretation of 1972 ASCS 1:20,000 panchromatic photography. Delineation of vegetative types on the reclaimed surface-mined areas was not completed at the same time, however. Preliminary field survey indicated that mined areas has undergone extensive changes since the 1972 ASCS photographic mission, thus necessitating more recent photo coverage for accurate vegetative cover classification within the reclaimed areas.

Vegetative ground truth survey was begun in February, 1975. Ground truth survey of forest types was completed by May 1, 1975 by Mr. Hammetter and Roger Horseman, the latter Assistant Forest Superintendent of the University's 15,000 acre Robinson Forest. This survey, a one-time, one plot per acre inventory of forested types, collected species, diameter, merchantable height, total height, and crown closure per cent data. Additional vegetative ground truth information is available for the University-owned study watersheds from a system of permanent inventory plots on these watersheds.

Receipt in May of 1:24,000 MSS and CIR imagery from the April 7, 1975 NASA aircraft overflight of the study areas permitted vegetative typing of the reclaimed sites. After type delineations were completed, Mr. Hammetter and Mr. Willis Vogel of the U.S. Forest Service, Berea, Kentucky, completed the field survey on these areas. Variables measured were species, ground cover percent, and crown cover percent.

Water quality and quantity information is being collected for each study watershed. Each watershed is instrumented with a weir, water stage recorder, and precipitation gauge. Weekly grab samples are taken at each weir and analyzed for several water quality parameters. Physical parameters measured include turbidity, temperature, and suspended sediment. Chemical parameters being analyzed include dissolved oxygen, alkalinity, pH, conductivity, calcium,

magnesium, sodium, potassium, sulfates, and nitrates. Recent analyses also include determinations of total coliform, fecal coliform, and fecal streptococcus. Such data are maintained on electronic data storage tapes and are available for retrieval and analysis.

The three privately-owned watersheds are monitored by U.S. Forest Service personnel who are cooperating with the Department of Forestry by providing information for use in this and other water quality studies jointly conducted by the two agencies. The three University-owned study watersheds are monitored by Department of Forestry personnel.

Dr. Wittwer is currently mapping the soils of the study watersheds, as well as conducting chemical analyses of soil samples taken from within the various vegetative type classifications in the reclaimed mine areas.

Personnel from the U.S. Geological Survey are presently conducting field work to update geologic mapping in Breathitt County in which the study areas lie. The Department will acquire this information when it becomes available and thus have up-to-date geological information for the study areas.

Imagery and imagery analysis

Color infrared and multispectral imagery from April and September, 1975, NASA aircraft overflights of the study areas have been made available to the Department by NASA personnel at Marshall Space Flight Center. These flights provide prefoliar and foliar ground conditions for imagery analysis. However, prefoliar MSS coverage of the study areas was incomplete due to double exposures over two of the study watersheds and inadequate coverage of a third watershed. Foliar imagery coverage is complete for both MSS and CIR imagery; but due to haze conditions at the time of the overflight, the blue band of the MSS imagery is washed out and essentially unusable.

Color infrared and multispectral imagery from the aircraft overflights, and LANDSAT imagery, will be used for land classification and change detection.

Land classification and change detection should probably be handled through the use of overlays and base maps. Unfortunately, the Department is somewhat inadequately equipped for data transfer between different map or photo scales. The Department's opaque projector or vertical sketchmaster could be utilized for such data transfer, but more efficient data transfer between scales could be accomplished with equipment such as B & L's Zoom Transfer Scope or K & E's Reflecting Projector. Such equipment would allow scale changes to be more readily matched and would enable the Department to prepare display products not possible with present equipment. The Department will prepare such data products as are possible with present equipment; but since funds are not available for additional equipment purchases, some data products of potential use to various state agencies and other user groups will not be available.

Aircraft and satellite multispectral imagery is being color enhanced with the I²S Color Additive Viewer on loan to the Department by NASA. The resultant enhanced imagery will be utilized to supplement the data yield of the primary imagery.

Color additive viewing can provide natural color, color infrared, or a variety of other color renditions. The addition of color through this process provides color information to the interpreter, without the need for additional photographic missions. This is perhaps the most significant benefit of color additive viewing of multispectral imagery.

Color additive viewing can increase contrasts among varying land uses, thereby allowing more accurate classification and location of these land uses. Because LANDSAT satellites provide repetitive coverage of any area, changes in land use, over time, may be evident in the imagery or color additive renditions. Such changes might be noted through use of overlays superimposed upon a land use base map.

Several types of land use change are indicated by LANDSAT imagery and color composites. Areas burned by forest fires are visible on the imagery and may be placed in time through periodic examination of the sequential LANDSAT coverage of an area. Surface mined areas, and the amount of reclaimed land within these areas, may be estimated from LANDSAT imagery and the changes noted on a suitable base map. Areas disturbed by natural catastrophes, such as floods or tornadoes, are visible on LANDSAT imagery and color composites. Such information might be valuable for damage appraisal for disaster aid or the like. Defoliation of large areas of forest through insect or disease attack may be apparent from satellite imagery examination. LANDSAT imagery and color composites appear to show varying suspended sediment loads in lakes and reservoirs. Color enhancement of negative transparencies appears to hold particular promise for water resource and tornado damage analyses.

One problem we have encountered with the color additive viewing process is that of improper registration of satellite imagery chips in the Viewer. A fully-equipped I²S Viewer would include a satellite chip holder as an accessory. The chip holder has adjustment screws to align the chips properly. The Department planned to purchase such a holder, but the \$2000 price for such an accessory proved prohibitive. Image chips are now fastened to a roll of clear acetate utilizing a templet for proper registration. Such a procedure, even with extreme care, does allow some misregistration of images, due both to human error and to possible dimensional changes in the carrier medium.

Manual densitometry of LANDSAT transparencies does not offer the capabilities of computer analysis of LANDSAT digital tapes, but it does hold promise for evaluating land use changes. The amount of revegetation of surface mined areas may be correlated with density signature changes in surface mined areas. Burned areas register darker than unburned areas on LANDSAT positive transparencies, and severity of burn may be indicated by density signature or time duration necessary for the area to return to a pre-burn signature. Presence of suspended sediment in lakes and reservoirs is often visible on LANDSAT imagery. Density signature data may reflect the amount of suspended sediment present.

Density signature data have been collected for the study areas from the April 1:24,000 CIR and MSS NASA aircraft overflight imagery and from cloud free LANDSAT 1:1,000,000 and 1:3,369,000 MSS positive transparencies. Densitometry of the September CIR and MSS overflight imagery has yet to be completed. Processing of available densitometer data for computer analysis is proceeding, but continues to be the bottleneck in the completion of the

density signature analysis of the available data as well as in the completion of other project objectives.

Even with such problems, further research into LANDSAT imagery, imagery enhancement, and densitometry applications may indicate expected or potential economic and/or other resource management impacts at local and regional levels.

Meetings and communications

Department of Forestry personnel attended a meeting in Frankfort, Kentucky in December, 1974 to participate in discussions on a small drainage area study being undertaken by the Bureau of Highways. It was determined that study areas under the highway project could not be included in the Department of Forestry NASA project, due to a lack of water quality data.

Department of Forestry personnel met with Dr. C.T.N. Paludan of NASA in Huntsville, Alabama in January, 1975 for discussions about project activities. Subsequent phone conversations with Dr. Paludan and with Mr. Sanford Downs, also of NASA, Huntsville have kept both agencies informed of project activity. Further discussions with Mr. Downs were conducted in August, 1975 when Dr. Graves and Mr. Hammetter went to Huntsville to pick up the I²S Viewer being loaned to the Department.

A meeting was held with Oak Ridge National Laboratory personnel in January, 1975 to discuss possible areas of cooperation. Personal contacts have been maintained with ORNL personnel via letters and phone conversation.

Meetings with State Division of Conservation and Strip Mine Reclamation personnel in January, 1975 focused on the information needs of these agencies. Visits by personnel from these agencies to the Forestry Department in June and November for demonstrations of equipment operation and capabilities, as well as numerous phone conversations throughout the year, have kept these agencies informed of research efforts and progress.

A meeting with U.S. Forest Service personnel in Berea, Kentucky in February, 1975 resulted in assistance with a water quality computer programming problem and in a pledge of assistance with ground truth survey of surface mined areas within the study watersheds. This ground survey assistance was rendered in June, 1975 by Mr. Willis Vogel, U.S.F.S., Berea, and gratefully acknowledged. Additional discussions have also been held between the two agencies.

Department of Forestry project personnel attended the Southeastern Remote Sensing Symposium held in Athens, Georgia in January, 1975. Information was gained about on-going projects and the possible applications of procedures and results from these projects to the Department's project. Similar information was obtained from the symposium on Machine Processing of Remotely Sensed Data held at LARS, Purdue, University in June, 1975 and attended by Mr. Hammetter.

Drs. Coltharp and Wittwer, and Mr. Hammetter attended the Northeast Forest Soils Conference held in August, 1975 at Slade, Kentucky. Included in the conference activities was a tour of surface mining and reclamation activities in the vicinity of the two partially surface mined study watersheds — Miller Branch and Mullins Fork.

Mr. Ed Swenson, U.S. Forest Service, Little Rock Arkansas; Mr. James McDivott, Economic Research Service, East Lansing, Michigan; and Mr. J.R. Farson, Jr., Division of Conservation, Frankfort, Kentucky, met with Drs. Coltharp and Graves and Mr. Hammetter to discuss how research efforts under this project might benefit their agencies. Further discussions are expected.

A summary of our research under this project was presented to C.S.R.S. reviewers on October 15, 1975 during their review of the Forestry Department's federally-funded research programs. College of Agriculture Associate Deans G.W. Stokes and C.O. Little were also in attendance during the review.

Dr. Donald A. Blome of the Institute of Mining and Minerals Research, Lexington, Kentucky, discussed this and associated research projects with Drs. Coltharp and Graves and Mr. Hammetter in October, 1975. Further meetings and discussions with Dr. Blome are planned.

Forestry Department faculty attended the Governor's Conference on Forestry held October 23-24, 1975 in Lexington. Interactions among those in attendance accounted for an appreciable exchange of knowledge and ideas. As a result of one such interchange, Mr. Jack Rhody, Assistant Director of Fire Control, Frankfort, is planning to visit the Department for a demonstration of the capability of LANDSAT imagery to show burned areas in Kentucky. Although the Governor presented opening remarks, his attendance at the conference was brief and there was no opportunity for personal interaction with him.

Dr. Graves and Mr. Hammetter attended the Fort Belvoir Workshop for Environmental Applications of Multi-Spectral Imagery held in November, 1975, at which Dr. Graves presented a paper entitled "Utilization of Remote Sensing Techniques to Detect Land Use Effects on Wildland Water Quality." A copy of this paper can be found in Appendix A.

On December 4, 1975, Dr. Graves presented a paper entitled "Densitometer and Color Additive Interpretation of Remotely Sensed Imagery" at the Society of American Foresters, Kentucky - Tennessee Section Meeting. Theme of the meeting was "The Status of Aerial Photography in Tennessee and Kentucky." SAF members present were also able to see demonstrations of color additive viewing and densitometry, as the Department displayed the I²S Viewer and densitometers. Considerable interest was expressed by the participants. Copies of the proceedings of this meeting were given to the registrants and are also being sent to SAF Remote Sensing Working Group members across the country. A copy of this paper is found in Appendix B of this report.

Dr. Coltharp will present a paper entitled "Use of Remote Sensing to Determine Effects of Land Use Changes on Water Quality" at the 42nd Annual Meeting of the American Society of Photogrammetry to be held in February, 1976 in Washington, D.C.

EXPENDITURES

Expenditures listed below are totals through December 12, 1975.

<u>Category</u>	<u>Expenditure</u>
Travel	\$ 628.29
Wages	\$ 10,225.04
Current Expenses	\$ 569.44
Equipment	\$ 2,301.95
	<hr/>
Total	\$ 13,724.72

Total expenditures listed above are lower than were expected for the initial contract period and much lower than those expected for the second year of Contract NAS8-31006.

Funds for data processing will be necessary, as data correlation efforts will require significant processing expenditures. As data are processed and results become available for presentation to interested groups, travel costs will increase. Travel costs will also increase due to project expansion to include analyses of other land uses and the need to travel to these areas to obtain necessary ground truth information. Current expenses will increase with the acquisition of additional LANDSAT imagery and other supplies connected with analysis and display of imagery and imagery products.

**UTILIZATION OF REMOTE SENSING
TECHNIQUES TO DETECT LAND USE
EFFECTS ON WILDLAND WATER QUALITY**

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BIOGRAPHICAL SKETCH

The authors are Assistant Professor, Associate Professor, and Research Specialist respectively with the Department of Forestry, University of Kentucky, Lexington. Graves and Coltharp received their Ph.D. degrees from the University of Kentucky and Michigan State University respectively and Hammetter received his M.F. degree from Iowa State University. Dr. Graves specializes in forest inventory, forest economics and integrated resource management; Dr. Coltharp in watershed management and forest hydrology; and Mr. Hammetter in photo interpretation and remote sensing. Collectively the authors have 38 years of experience in forestry and have professional affiliations with the Society of American Foresters, American Forestry Association, American Water Resources Association, Soil Conservation Society of America, and American Society of Photogrammetry. The authors are principal investigator, co-investigator, and photo interpreter respectively for the NASA funded "Remote Sensing of Land Use Practices on Water Quality" project.

ABSTRACT

Multistage sampling techniques are being utilized to determine and monitor land use changes and the effects of such changes on water quality in the Cumberland Plateau region in eastern Kentucky. Land use practices being monitored include forest fertilization, logging, and surface mining. Vegetation inventory and physical, chemical, and bacteriological water quality data provide the ground truth for correlation efforts.

Manually-operated spot densitometers are being used to identify vegetation signatures on LANDSAT multispectral and seasonal 1:24,000 color infrared and multispectral transparencies. Densitometry data will be correlated with ground truth information in the attempt to develop a water quality prediction model. Color additive viewing of satellite and aircraft multispectral imagery is being evaluated for land use monitoring and change detection potential.

INTRODUCTION

Remote sensing has potentials for providing effective survey techniques to monitor land use at a reasonable cost. The Department of Forestry, in cooperation with the National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama, is working to assess the capabilities of multistage - multispectral aerial photography and satellite imagery to detect and monitor land use practices and to determine effects of these practices on water quality.

Land use classification efforts utilizing LANDSAT multispectral CCT's or transparencies and/or aircraft imagery are being undertaken by numerous researchers. Research by Chase and Pettyjohn (1973) in the area of strip mine classification and ecological effects of strip mining in eastern Ohio is of particular interest to this study, since strip mining constitutes a major land use in eastern Kentucky and is one of the land

uses considered in this study. Though incomplete, their research indicates that identification of secondary effects of acid mine drainage and stream sedimentation resulting from erosion will be their most difficult task.

Efforts to use satellite and/or aircraft imagery for water quality predictions are few in number and generally oriented to large water bodies where sediment flow and dispersion or thermal plumes are visually apparent. One research project not oriented to large water bodies is that of Retson and McMaster (1974). They have developed a first-generation nonpoint source water quality model, regionalized to the Tennessee Valley, that indicates concentrations of most standard water quality constituents can be simulated within \pm fifty percent on the average. Little or no research has been undertaken in the attempt to develop water quality models based upon densitometry of imagery where the water resource itself is not readily apparent. Density information in this case must be derived from the joint effects of vegetation, topography, and aspect, among others. Driscoll and Francis (1971) have found that generalized plant communities identify reasonably well by optical density measurements through a green filter on small-scale color infrared transparencies taken in the fall. They, and others, have also found that the greater the homogeneity of the image of interest, the greater the possibility of automated interpretation by densitometry.

The objectives of our project are: (1) to establish ground truth parameters that typify vegetative cover of disturbed and undisturbed watersheds in eastern Kentucky's Cumberland Plateau; (2) to monitor water quality parameters of watersheds utilized in establishment of ground truth data; (3) to establish imagery signatures of known land use areas utilizing manually-operated spot densitometers; (4) to determine the relationship of imagery signature data with water quality data; (5) to develop capability to predict water quality emanating from forested and surface mined watersheds based upon above relationships; and (6) to evaluate cost effectiveness of predicting water quality values utilizing multistage imagery sampling techniques.

STUDY AREA

The study area is centrally located within the Cumberland Plateau in Kentucky and combines the resources of the University of Kentucky's 15,000 acre Robinson Forest and an adjacent drainage. The Cumberland Plateau of eastern Kentucky serves as a watershed for central and eastern Kentucky and portions of West Virginia, Virginia, Ohio, and Tennessee. Climax vegetation of the Plateau is mixed mesophytic forest. In an undisturbed condition this vegetation provides excellent protection to easily erodable soils that are subject to characteristic periods of intense precipitation. The area is isolated and sparsely populated, due predominantly to steep topography. Prominent land uses are hillside farming, forest harvesting, and strip mining.

The six primary watersheds used in the study comprise an aggregate area of 539 hectares (1330 acres). All study areas are forested; however two watersheds have been partially surface mined and are in various stages of reclamation. Another watershed has been fertilized with 82.6 kilograms/hectare (450 pounds/acre) of ammonium nitrate. Another watershed is designated for timber harvesting in the summer of 1976. The other two watersheds will be used as controls.

METHODOLOGY

Water quality

Several years of water quality and quantity information are available for each study watershed. One-hundred-twenty degree V-notch, broad crested weirs were constructed and instrumented by the U.S. Forest Service in 1967 for the three privately-owned

study watersheds. These watersheds include the two surface mined watersheds and one control watershed. Similar weirs and instrumentation were established by the University in 1971 on three study watersheds located in Robinson Forest. Instrumentation in each watershed includes a water stage recorder located at each weir and an eight inch weighing type recording precipitation guage located in a forest opening within the watershed.

Weekly grab samples are taken at each weir and analyzed for several water quality parameters. Physical parameters measured include turbidity, temperature, and suspended sediment. Chemical parameters being analyzed include dissolved oxygen, alkalinity, pH, conductivity, calcium, magnesium, sodium, potassium, sulphates, and nitrates. Recent analyses also include determinations of total coliform, fecal coliform, and fecal streptococcus. Such data are maintained on electronic data storage tapes and are available for retrieval and analysis.

The three privately-owned watersheds are monitored by U.S. Forest Service personnel who are cooperating with the Department of Forestry by providing information for use in this and other water quality studies jointly conducted by the two agencies.

Vegetation

Detailed vegetative ground truth information is available from a system of permanent inventory plots on the University study watersheds. Additionally all study areas were stratified and typed on aerial photographs by species, size, and density classes and randomly sampled within types utilizing a one-time, one plot per acre inventory of forested types. Data collected included species, diameter, merchantable height, total height, and crown closure percent. Those variables measured in the non-forest types were species, ground cover percent, and crown cover percent. The permanent inventory plots on the University study watersheds will be used for land use and stand change analyses.

Imagery

Color infrared and multispectral imagery from April and September, 1975, NASA aircraft overflights of the study areas have been made available to the Department by NASA personnel at Marshall Space Flight Center. These flights provide prefoliar and foliar ground conditions for imagery analysis.

Color infrared and multispectral imagery from these overflights, and LANDSAT imagery, will be used for land use classification and change detection. In addition, aircraft and satellite multispectral imagery will be color enhanced with a color additive viewer. The resultant enhanced imagery will be utilized to supplement the data yield of the primary imagery.

The Macbeth Model TD-528 densitometer offers combinations of four filters and three apertures, while the TD-500 offers only one filter and two apertures. All aperture-filter combinations are used with all available imagery-wavelength bands of aircraft and satellite transparencies to determine vegetation signatures. Data collected, taking one reading per acre per type with the above aperture - filter combinations, are being used in the correlation analyses.

Densitometry of satellite imagery offers the exception to the one reading per acre per type. The smallest aperture available on these densitometers is one millimeter in diameter. The ground area represented by this circular area is 2000 acres on the

1 = 3,369,000 imagery and 192 acres on the 1 = 1,000,000. Quite obviously one reading per acre per type is impossible. Consequently one reading for the total study area is taken on the 1 = 3,369,000 imagery and one reading per study watershed on the 1 = 1,000,000. Some overlap of readings from adjacent watersheds occurs, since the study watersheds vary in size from 100 to 327 acres and are not circular in shape. Overlap will be minimized but it cannot be completely eliminated.

The relationship between densitometer data, ground truth, and water quality data will be examined in the attempt to derive a water quality - land use prediction model.

PRESENT STATUS

A vegetative ground truth survey of the study areas is complete and is being processed for computer analysis. Water quality information is available for retrieval and analysis. Densitometer data from all LANDSAT multispectral imagery yielding cloud free coverage of the study areas and from the color infrared and multispectral imagery from the April overflight are being processed for signature determination and correlation analysis.

Densitometry of the September overflight imagery and evaluation of the utility of color additive viewing for land use classification and change detection is still incomplete. Development of a water quality prediction model and determination of the cost effectiveness of the sampling techniques cannot be completed until the data are processed into computer format.

SUMMARY

Multistage sampling techniques are being applied in an attempt to establish vegetative signatures and the relationship between these signatures and water quality. Water quality determinations and ground truth information provide the bases for correlation efforts. The potential of manually-operated spot densitometers to yield data meaningful to water quality prediction is being studied. No definitive statement of this potential is possible at this stage of analysis.

References

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**DENSITOMETER AND COLOR ADDITIVE INTERPRETATION
OF REMOTELY SENSED IMAGERY**

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Introduction

The art and science of aerial photo interpretation in forestry has evolved within a relatively short period of time. Only fifteen years ago photogrammetry was offered as a graduate course. Black and white panchromatic film was the predominant film type in use at this time. Black and white infrared and modified infrared photography were developed and implemented more recently.

As faster film emulsion speeds were developed, color photography began to gain higher acceptance. Since the costs of color photo missions and imagery are very little more than those for black and white, and since color films tend to yield additional interpretive information, color and color infrared films have tended to supplant black and white imagery in natural resource applications.

Present space age technology is adding even more dimensions to photography. Improved cameras and lens systems, as well as new film types, have developed. High flight aircraft and satellites offer large-area, single-print photographic coverage. New types of sensors, such as radar, thermal scanners, and multiband cameras capable of taking simultaneous pictures sensitive to different portions of the electromagnetic spectrum, are being utilized. Such developments have allocated conventional aerial photography and its interpretation only a portion of the larger art and science called "Remote Sensing."

These developments have, by necessity, created the impetus for development of a variety of instruments to be utilized in the interpretation of such imagery. Two such new analysis systems are densitometry and multispectral color enhancement. These systems should be of interest to the practicing forester. The equipment necessary for these systems is relatively inexpensive and the operating procedures rather simple. The utility of these systems is to be discussed.

Densitometry

Densitometry, as applied to photogrammetry, is the measurement of the density or solidness of a photographic image or scene as determined by the amount of light allowed to pass through the scene to some collector mechanism. It could also be defined as the measurement of the amount of light reflected from a point on an opaque print into a collector mechanism. For the majority of densitometry applications, film transparencies are required. These transparencies may be derived from black and white, b/w infrared, color, color infrared, multispectral, or other imagery types. The imagery may be obtained by camera, scanner, radar, or other signal generating device.

Just as different lens filters are used in aerial photography to yield different photographic effects, as in the use of a yellow lens filter to obtain modified infrared imagery; filters are used in densitometry to obtain density values keyed to the spectral response of an object in varying wavelength bands. Several readings may thus be obtained from an object on one photo by simply changing densitometer filters. Density values associated with any given set of filters become the "density signature of the object."

Additional components of this signature can be gained through the utilization of different densitometer aperture sizes. A series of small diameter aperture readings will probably vary more than a series utilizing a larger aperture, within a given land use classification or vegetation type. The larger aperture tends to smooth out the density variations inherent within any land classification unit or vegetation type.

Utilization of filter and aperture combinations in densitometry allows the expansion of one-component density signatures to more definitive multiple-component signatures. Additional signature components may be added by using additional imagery types, varying imagery scales, and/or multi-temporal coverage of an area.

For those who have not kept abreast of recent developments in remote sensing, the above discourse may sound quite complicated and confusing. However, sound economic arguments can and are being developed that indicate not only are such procedures feasible; they may even become necessary as the costs of labor and travel continue to increase.

Time spent in ground survey is costly. If inexpensive methods can be found to eliminate some of the ground work, time and money saved will be available for other uses. If photographic density signatures can be correlated to ground conditions, such as timber types and/or volumes, less field work would be required to get timber inventory data necessary for management decisions. If density measurements indicate stand conditions, then a photo interpreter might delineate forest types and a technician complete the densitometry and evaluate timber volumes based on a greatly reduced ground plot inventory. Densitometry could eliminate the difficult photo measurements of crown closure, crown diameter, and stand heights necessary for the utilization of standard aerial volume tables. Regional analysis of land uses with satellite imagery is possible. Land use classifications such as agricultural, forest, urban, or surface mined areas are possible whether utilizing computers or manually-operated spot densitometers. Many researchers have even been able to categorize and approximate the acreages of different crops with fair success utilizing computer analysis of repetitive LANDSAT digital tape coverage of a scene.

Computer processing of LANDSAT digital tapes offers fairly good classification and subsequent acreage determinations for relatively large land use categories, probably on the order of ten acres or more. Forest classification, unfortunately, can only be broken into three categories: hardwoods, conifers, and hardwood/conifer mixtures; and only the forest classification as a whole can be reliably estimated from digital tape classifications.

Some misclassification of all land use classes will occur, just as it would with manual interpretation; but for rapid regional analyses of land uses, computer processing of LANDSAT digital tapes offers significant potential. Use of digital tapes rather than data derived from density measurements of LANDSAT transparencies will yield more accurate density signatures and acreage determinations for at least two reasons. Possible film developing variations between and within scenes are avoided, and tapes can be examined one digital picture element at a time, which roughly corresponds to a one and a half acre unit.

The largest standard film transparencies available from the EROS Data Center have a scale of 1:1,000,000. Manual densitometry of this imagery utilizing a one millimeter densitometer aperture would yield a density signature for an area 192 acres in size. This signature area is considerably larger than that possible with LANDSAT digital tapes.

Manual densitometry of LANDSAT transparencies does not offer the capabilities of computer analysis of LANDSAT tapes, but it does hold promise for monitoring land use changes.

Progress in strip mine reclamation may be indicated through imagery density changes as vegetation on reclaimed areas increases. The amount of revegetation may be directly correlated with density signature change.

Large areas burned by forest fires are visible on LANDSAT transparencies and are characterized by greater signature densities than surrounding unburned areas. There may be some potential for determining the severity of burn by density signatures either in absolute density values or as a function of the time necessary for an area to assume a pre-burn signature.

Changes in timber stands, whether due to logging, insect or disease attack, or catastrophic events such as tornadoes, may be noted on LANDSAT imagery. Perhaps extent or severity of damage may be indicated by modification of density signatures as compared to signatures of comparable undisturbed areas.

Presence of suspended sediment in lakes and reservoirs is often visible on LANDSAT imagery, and density signature data from this imagery may correlate with the amount of sediment present. The Department of Forestry, in cooperation with the National Aeronautics and Space Administration, is attempting to use satellite and aircraft imagery density signature data from six study watersheds to develop a water quality prediction model. Vegetative ground truth and water quality data provide the bases for correlation efforts.

The need exists to establish slope and aspect relationships if densitometry is to yield meaningful signature data. In the Cumberland Plateau, as in other high relief areas, aspect and degree of slope affect densitometer measurements significantly. Fortunately, when dealing with natural timber stands, tree species, and to a lesser extent, timber stand densities, are correlated strongly with aspect. In the case of natural timber stands, the species-stand density-aspect correlations reduce but do not eliminate the need to apply some correction factor to densitometer data to adjust for aspect-slope impact. Artificially-established forest stands, such as plantations, will not necessarily adhere to the species-aspect relationship, and aspect-slope corrections to densitometer data assume greater importance in species identification studies.

Color Additive Viewing

Any discussion concerning color additive viewing must assure that everyone understands what is meant by multispectral imagery, since color additive viewing is the addition of color to such imagery.

Multispectral imagery consists of a set of pictures or images taken at the same instant. Each picture in the set is the product of a different set of lens filters. Each image on the film has been formed by wavelengths from a restricted portion of the electromagnetic spectrum. The multispectral imagery from LANDSAT consists of images from four bands: green, red, and two near infrared bands. Four-band aircraft multispectral imagery usually includes blue, green, red, and near infrared bands.

The blue, green, and red bands usually yield greater tonal and density contrasts among land uses than near infrared bands. Red and near infrared bands, however, generally

show greater topographic and water resource details than blue and green wavelength bands. The blue band, while yielding land use contrasts, is very susceptible to atmospheric haze. Imagery from this band may be rendered virtually unusable if high haze conditions are present at the time of imaging.

Color additive viewing of multispectral imagery may be accomplished by utilizing a system such as the International Imaging System viewer on display at this meeting or by various exotic combinations of viewers and computers available from many companies. The basic purpose of color additive viewing is to enhance image detail o. contrasts so more information might be gleaned from the imagery by the photo interpreter or other imagery user. Addition of color, through the color additive process, provides color information to the interpreter, without the need for additional photographic missions. This is perhaps the most significant benefit of color additive viewing of multispectral imagery.

Color additive viewing can provide natural color, color infrared, or a variety of other color renditions. The number of possible color combinations is greater with computer enhancement systems than for manual systems, but in most cases satisfactory image enhancement can be achieved with manual systems at lower costs.

Color additive viewing on a manual viewer can be performed with 1:3,369,000 multispectral satellite chips and with aircraft multispectral imagery taken with a multi-band format. Larger scale satellite imagery cannot be used because most manual viewers are not designed for the greater size of larger scale satellite transparencies. Aircraft imagery of various scales can be used since image chip size remains constant. Flying altitude or focal length changes are used to produce aircraft imagery of different scales. Obviously, flying altitudes and camera focal lengths cannot be changed as readily in satellite operations.

The question that must be asked is: what potential does color additive viewing have for assisting resource managers in resource analyses and decision making?

Color additive viewing can increase contrasts among varying land uses, thereby allowing more accurate classification and location of these land uses. Color enhancement of LANDSAT imagery may be used for regional, large-block land use classification and change analysis. Because LANDSAT satellites provide repetitive coverage of any area, changes in land use over time may be evident in the imagery or color additive renditions.

Large areas burned during the fall fire season are visible on winter and spring LANDSAT imagery and color composites. Whether these burned areas will be visible during the growing season and if so, for how long, are questions under investigation by the Forestry Department.

The change in surface mined areas, either due to increased mining or increased reclamation activities, may be apparent on satellite imagery. Studies conducted with LANDSAT digital tapes have indicated that areas of surface mining and partial reclamation can be identified and quantified with fair accuracy through computer analysis. While color additive analysis of satellite multispectral transparencies cannot quantify surface mining activities, such analysis can locate areas of surface mining and permit some estimate of the influence of this activity on other land uses in the region.

LANDSAT imagery appears to show suspended sediment in lakes and reservoirs, and color

additive viewing gives the sedimented and unsedimented areas different color signatures. Perhaps the difference in wavelengths of the different colors portrayed may be correlated to the difference in sediment load in the water bodies.

LANDSAT imagery will be analyzed directly and through color additive viewing to determine whether the current pine beetle infestations in southern Kentucky can be detected and monitored by satellite.

Aircraft multispectral imagery offers the interpretation capabilities of conventional panchromatic aerial photography plus the availability of black and white infrared and the possibility of natural and false color renditions through color additive viewing. One can thus use conventional photo interpretation techniques on imagery that offers more than one photographic medium.

The color additive process would necessitate the utilization of some form of color additive viewer. A viewer such as the one on display by the Forestry Department costs approximately \$11,000. Thus, some monetary investment above the cost of imagery acquisition must be made to get full value from multispectral imagery.

Some of the potential interpretation products from aircraft multispectral imagery include timber typing and stratification, detection of vegetation stress through color additive analysis, and soil mapping.

Summary

Densitometry and color additive viewing of multispectral imagery, whether by computer processing or manual techniques, appear to offer significant potential benefits to natural resource managers. LANDSAT imagery appears useful in regional, large-area analyses of land uses and land use change. Three problem areas appear to restrict the usefulness of the LANDSAT imagery, however, and two of these are connected with the distance factor in satellite applications.

Image resolution is not equal to that of photography normally used by most resource managers and degradation of image quality results with enlargement.

A second problem is that repetitive coverage offered by LANDSAT may not be as useful as the timetable of repetitive coverage would imply. Kentucky and Tennessee lie in a zone where only three to eight days of cloud-free coverage per month can be expected. Thus, if the satellite happens to pass over the area of interest on one of these days, cloud-free coverage results. If not, then the satellite image will yield cloud patterns that obscure a portion or all of the ground detail.

A third problem is the time lag between date of imaging and date of availability to the EROS Data Center and thence to possible users. According to the Data Center a four to eight week time lag exists between these two dates. For significantly after-the-fact analysis of land use or land use change, this time lag may not be too important, but for near-real-time applications of this data, this time lag is fatal.

LANDSAT imagery can be a useful tool in the management of earth resources. Its use, however, is subject to the limitations described above. Potential use of this imagery should be evaluated in light of these factors.

Aircraft multispectral imagery appears to offer new dimensions and possibilities to the photo interpreter. Coupled with color additive viewing, this imagery can provide the interpretive benefits of color imagery from a black and white product.

Multispectral imagery is not without some disadvantages. As compared to conventional photography, multispectral imagery requires additional frames and hence additional film, to achieve similar imagery coverage of an area. The multiband format necessitates a smaller image area within each band in a frame. An imagery interpreter will thus have to examine more frames to get information about an area. This means more time and money spent in moving photos around. Also, with smaller frame size, additional flight lines and flying time will be necessary to achieve required sidelap percentages.

New imagery products and analysis techniques, such as the ones described, are being developed and tested throughout the world. The applications to earth resources problems that may result from this new technology cannot be quantified; neither can they be discounted.